COLORED STONES

ASSIGNMENT 6

REFLECTION, REFRACTION, AND LUSTER

IDENTIFICATION, PRODUCTION, MARKETING, BUYING

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I. INTRODUCTION.

One of the most important areas in the study of gem materials concerns the optical properties of the various gem species. Prior to the introduction of optical gem-testing instruments, testing procedures for identifying stones were limited mainly to destructive and very unreliable tests that constantly exposed the jeweler to criticism and even law suits. Lack of knowledge of gem identification is a major reason why the majority of jewelers have simply avoided handling colored stones, other than perhaps a limited number of standard, inexpensive stone-set rings. A knowledge of the properties of colored stones and of identification procedures constitute fundamentals that should be common knowledge to every jeweler.

A clear understanding of optical properties and their roles in identification and grading begins with a study of the nature of light and its behavior in the various gems. Optical properties are defined as those properties resulting from the effect a given substance has on light as it is transmitted by and/or reflected from it. These properties permit accurate, safe and rapid identification of both mounted and unmounted stones. The following discussion of the nature of light includes only the essential information that is needed in the study of gems and in the application of this knowledge to identification, grading and appraisal procedures.

II. THE NATURE OF LIGHT.

Visible light, whether emitted by the sun or a candle or a light bulb, is a form of RADIANT ENERGY, so called because it radiates or spreads out from its source. The portion of the sun's radiant energy spectrum that we can see represents only a small fraction of the total; the remainder is invisible. All forms are included in the ELECTROMAGNETIC SPECTRUM, including infrared light, visible light, ultraviolet light, radio and telvision waves, X-rays, and cosmic rays. Figure 1 shows the electromagnetic spectrum. All of these forms of radiant energy have two properties in common: (1) they travel in air at substantially the same rate of speed, 186,300 miles per second, and (2) they may be thought of as traveling a wave motion. This wave motion is similar to water waves in many ways although it is different in others. A WAVELENGTH is the linear distance between a point on one wave and the exactly corresponding point on the next wave as illustrated in Figure 2. Although these is no distinct dividing line between the various forms of radiant energy, they are separated by their differences in wavelength. Radio waves may be as much as six miles long, whereas cosmic rays, at the other end of the spectrum, are only on the order of one-trillionth of a centimeter long! (See Figure on next page)

ELECTROMAGNETIC SPECTRUM

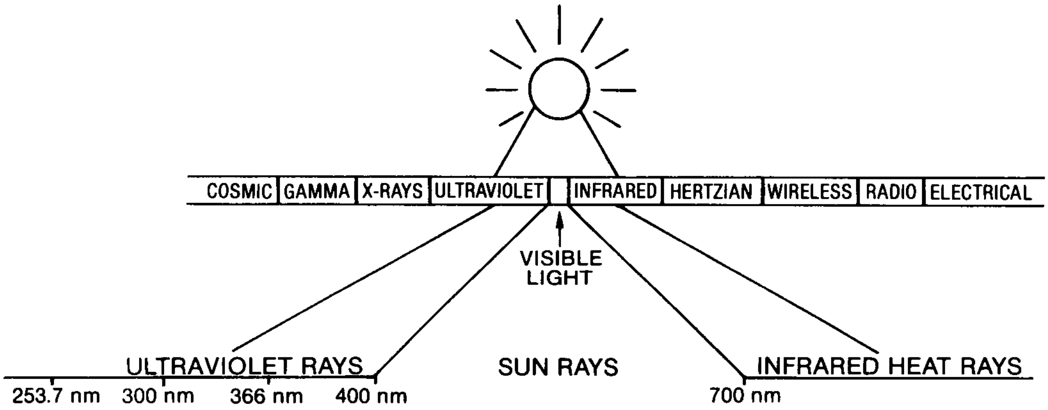

Figure 1

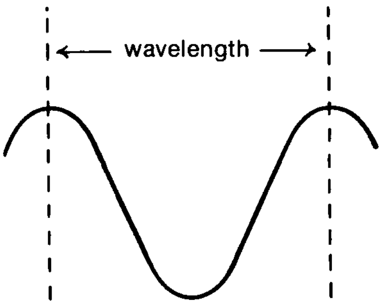

Figure 2

The portion of the electromagnetic spectrum that is of primary concern to the gemologist is visible light. Visible light ranges from the longest wavelength (red) through orange, yellow, green and blue, down to the shortest wavelength (violet). When these wavelengths are mixed together, as we ordinarily see them, the result is WHITE light. The wavelengths of the visible spectrum range from approximately 700 nanometers for red to approximately 400 nanometers for violet. A nanometer (abbreviated n.m.) is one millionth of a millimeter (Figure 1). Some wavelength measurements are also quoted in angstrom units. An angstrom unit is one ten millionth of a millimeter. Thus, visible light ranges from 4,000 A.U. in the violet to 7,000 A.U. in the red.

III. SOURCES OF LIGHT.

There are two basic sources of light: INCANDESCENCE AND LUMINESCENCE. A solid mass may be an incandescent source of visible light, as when a metal is heated to a point where it begins to emit visible radiation. Thus, we say that a metal is "red hot" or is at a "white heat." An incandescent light bulb contains a tiny filament that is heated by electricity to a white-hot temperature. In contrast, luminescence does not involve high temperatures.

Materials may be stimulated to emit visible light by a form of radiant energy such as ultraviolet light; this is called FLUORESCENCE. A number of gemstones (particularly opal, kunzite and diamond) fluoresce in various colors when subjected to ultraviolet radiation. If the reaction continues after the stimulating radiation is removed, the resulting light is called PHOSPHORESCENCE. Although there are other forms of luminescence, fluorescence is the most important type.

IV. REFLECTION AND REFRACTION.

When a beam of light falls on a surface, such as a facet of a gemstone, part of the light enters the stone and part is reflected. Because the stone is denser than air, the light that enters the stone is slowed down and this causes it to be bent, or REFRACTED. Whether conscious of it or not, you have often seen refraction. When a straight stick thrust into water appears to bend, or when an object in a glass of water seems to be in a different place than you knew it to be, it is because of refraction. An experienced diamond man knows that imperfections in diamonds appear to be in other than their actual positions in the stone. One imperfection will often be seen at the same time through two, three or more facets and appear to be several imperfections, each in a slightly different position in the diamond.

To illustrate the nature of refraction and why it occurs, picture the beam of light as being similar to the long waves, swells, or breakers on a body of water moving toward a shoreline. The long lines or breakers are called WAVE FRONTS (A to B in Figure 3). The direction that a wave travels is at right angles to its wave front as shown by the arrows in Figure 3.

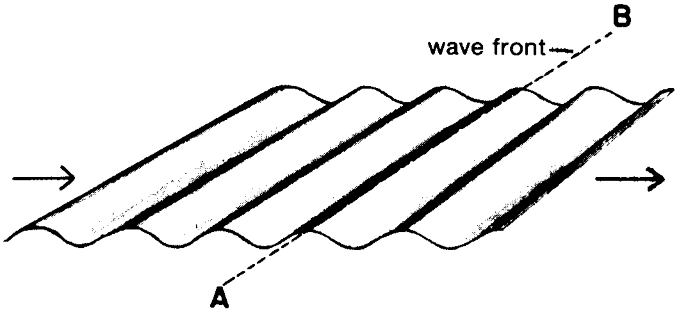

Figure 3

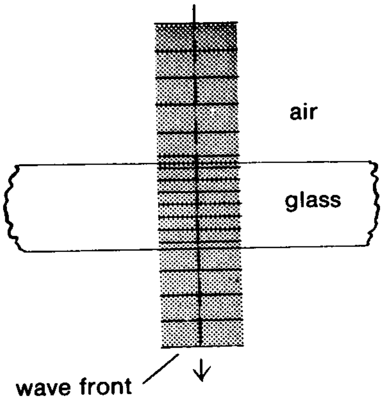

Figure 4

When the wave front of light strikes a window at right angles to the surface (Figure 4), it is immediately slowed down. The decreased velocity results in the shortening of the wavelength of the beam, as shown by the wave fronts placed closer together in the glass. When the beam leaves the glass, it immediately resumes its original speed and wavelength.

But suppose instead of entering the glass at right angles to the surface, it enters at an OBLIQUE (slanting or inclined) angle (Figure 5). As the left portion of the wave front enters the glass, it is slowed down, but the portion on the right, which is still in the air, continues at the same velocity. By the time the entire wave front is in the glass, its direction has changed as shown in Figure 5. The more optically dense the material that the light is entering, the more the light will be slowed down and the more the light will be bent. Just the opposite bending occurs when the light leaves the glass.

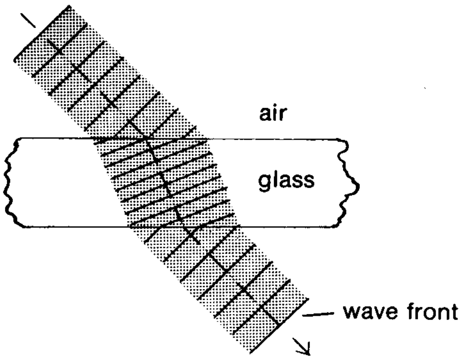

Figure 5

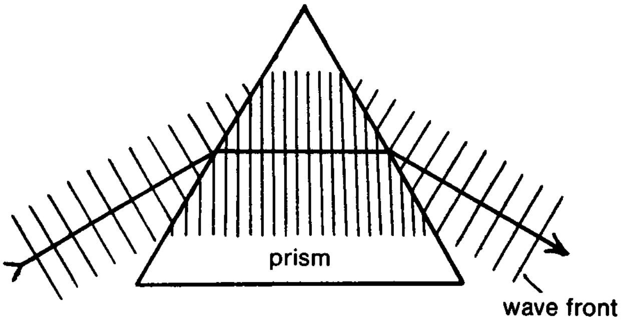

Figure 6

When the material through which the light passes has parallel sides like the window glass in the last two examples, the direction of the light when it leaves the material into the air will be the same as before it entered the material (see Figure 5). If the sides of the material are not parallel, as shown in Figure 6, the light will not return to its original path.

Not all the light that strikes a surface enters the material. Some of the light is bounced back to the eye, or REFLECTED (see Figure 7). This is what happens when light hits a mirror. Other surfaces usually do not reflect as much light as a mirror but some of the light is reflected nonetheless. If the light strikes the surface at an oblique angle, the angle at which the light is reflected from the surface is the same as the angle at which the light hits the surface as shown in Figure 7.

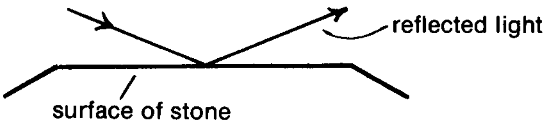

Figure 7

V. REFRACTIVE INDEX.

Optical density varies from material to material and thus from gem species to gem species. This is very useful in the identification of gem species. The optical density of zircon, for example, is much greater than that of quartz. This means that light is slowed down much more as it enters zircon than when it enters quartz. The comparative ability to slow down and thus to bend or refract light is called its refractive index (abbreviated as R.I.). Refractive index is defined as the ratio of the speed of light in air to the speed of light in a substance:

$$\frac{\text{Speed of Light in Air}}{\text{Speed of Light in the Substance}} = \text{Refractive Index}$$

For example, diamond has an R.I. of 2.417. This means that light travels 2.417 times faster in air than it travels in a diamond, the speed of light in a diamond being approximately 77,000 miles per second.

Refractive indices between approximately 1.35 and 1.81 are measured by an instrument known as a REFRACTOMETER. This instrument gives readings of refractive indices on a calibrated scale. For example, aquamarine beryl will show readings of about 1.57 to 1.58, and synthetic blue spinel shows an R.I. of 1.73 making the separation of these two stones easy. For this reason, the refractometer is probably the most important instrument that the gemologist uses.

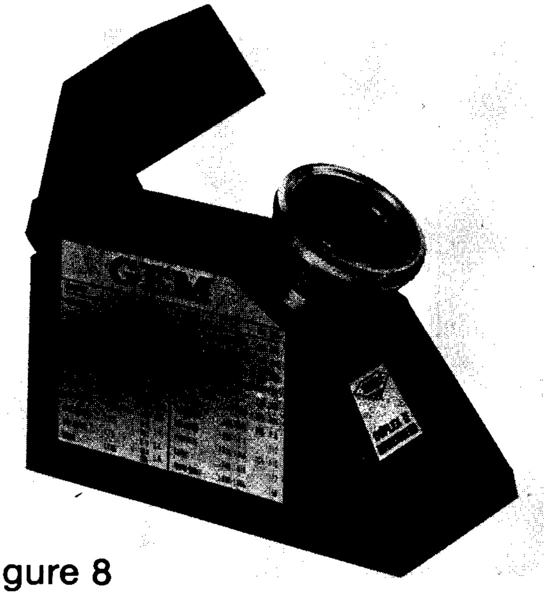

Figure 8

VI. LUSTER.

Luster may be defined as the appearance of a surface when it reflects light directly to the eye. The classification of luster depends on the following factors:

A. Quality of Reflected Light.

This factor is determined by the character of the reflecting surface, and may be subdivided into two general classes:

(1) PLANE REFLECTION (reflection from a flat, highly polished surface), and
(2) DIFFUSED REFLECTION (reflection from a dull surface such as this paper).

Sketch A in Figure 9 shows reflection of light at the same angle from a plane-polished surface; sketch B shows slight diffusion as a result of poor polish; sketch C shows highly diffused reflection from a rough, irregular surface.

There are vast differences in so-called plane-polished surfaces that are smooth to the unaided eye and to a 10x loupe. Stones polished too rapidly usually have minute parallel grooves that are visible under 10x. Even carefully polished stones of many species, because of brittleness or differences in hardness with direction, do not have really smooth surfaces. Surface irregularities affect luster materially by causing a beam of light to be diffused rather than reflected at one angle.

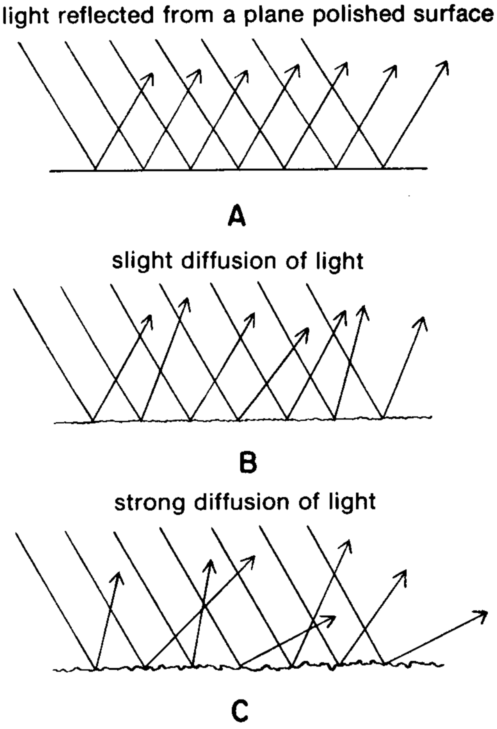
light reflected from a plane polished surface
A
slight diffusion of light
B
strong diffusion of light
C

Figure 9.

B. Quantity of Reflected Light.

Of all the light falling on a surface, the proportion reflected depends on the refractive index of the substance and the angle at which the light strikes the surface. When the approaching light is nearly parallel to the surface, the greater proportion of it is reflected. This can be likened to a flat stone on water: If the stone is dropped straight into the water, it sinks straight down, but it can be skipped across the water if it strikes the surface at a flat angle. Also, the greater the refractive index for any given stone, the greater the quantity of light reflected. Metals, because of their very high refractive indices, reflect almost all of the light that strikes them.

C. Body Appearance.

Some minerals exhibit an internal formation, or body structure, that affects their general appearance in reflected light. Since this structure seldom has any effect on the appearance of the polished surface, in gemology it is usually mentioned separately as body appearance. An example is the fibrous structure of tiger's-eye quartz, which gives a rough specimen of this material a silky appearance. When polished, tiger's-eye loses the silky appearance on its surface, but the effect is still visible in the body of the stone. This effect of body texture on surface luster is known as SHEEN.

The luster of any material, as pointed out above, depends on both the quantity and quality of light reflected from it. The majority of gems can be polished to present very nearly flat surfaces, and they will therefore show plane reflection. Some, however, because of their structure, cannot be polished to produce a truly flat surface. Jade, other than the finer qualities, is an example of the latter. The following are the principal kinds of luster:

A. Metallic.

This luster, which is shown by metals and a very few gem materials, notably pyrite, marcasite, and hematite is the most brilliant of all. It results from the plane reflection of a great proportion of all the light that falls on a surface.

B. Adamantine (diamondlike).

Adamantine refers to the surface appearance of those gemstones that exhibit plane reflection of a fairly large proportion of all the light that falls on them. Diamond is the outstanding example. Of the light that falls from all angles on a plane-polished surface of a diamond, approximately 30% is reflected. Other gems that approach an adamantine luster are zircon and demantoid garnet. Stones showing an adamantine luster have a very high refractive index, at least over 1.81. This is the highest luster that can be shown by a transparent stone.

C. Vitreous (glasslike).

This luster is characteristic of those gems that exhibit plane reflection but that reflect a smaller proportion (less than 30%) of the light that falls on them. The majority of gems show a vitreous luster. Examples are beryl, quartz, topaz and others with refractive indices between 1.50 and 1.81.

D. Greasy and Resinous.

These lusters are characteristic of those polished surfaces that are not perfectly flat but that approach flatness. Examples of a greasy luster are some rough garnets and peridots. However, these two gem materials, when carefully polished, exhibit very nearly perfectly plane surfaces; therefore, they usually show a vitreous luster. The usual commercial polishing methods used for jadeite and nephrite do not produce a perfectly flat surface; consequently, polished specimens have a slightly greasy luster.

The term resinous is sometimes applied to the more or less greasy luster of yellow resins or to any other yellow material resembling resin. Although a resinous luster can be seen on a fractured surface of amber, it can be polished to show a surface that is quite plane and thus exhibit a very nearly vitreous luster.

E. Waxy.

A waxy luster resembles greasy and resinous lusters, except that the surfaces on which it is seen are more irregular. Examples are poorly polished turquoise and most rough chalcedony.

F. Dull.

A dull luster can be described as the appearance produced by a very irregular, fine-grained surface. This page has a dull luster. A dull luster is typical of rough turquoise. It is never seen on well-polished surfaces of gems.

G. Silky.

This luster is produced by a fibrous body appearance. It is best seen on rough specimens of tiger's-eye. Polished tiger's-eye shows a vitreous luster on its surface, over-laying a fibrous body, and the resulting optical effect is known as a SILKY SHEEN.

H. Pearly.

Luster is described as pearly when the appearance is similar to that of a fine pearl. The luster of rough moonstone can be described as pearly, the characterisitc sheen of which is so named for want of a more appropriate term.

The most important lusters of polished gemstones are vitreous and adamantine. There is not a sharp dividing line between different lusters. No two gemstones have exactly the same luster. If all gemstones could always be polished to equally flat surfaces, luster would depend only on refractive index. Since this does not happen, some gemstones have higher or lower lusters than their refractive indices would lead one to expect. Topaz and almandite garnet both take an excellent polish and have lusters somewhat higher than their positions on the R.I. scale would suggest. Synthetic rutile and usually zircon have lusters below what their high R.I. would suggest.

To observe the luster of a gem, hold it so that the light from a lamp or window reflects off its surface. The intensity of the light, of course, will affect the intensity of the luster. If luster is being used for identification, the light source must not be of high intensity.

The brilliancy of a transparent gemstone depends on the intensity of its luster plus other factors to be mentioned later. Since brilliancy is a form of beauty that is admired by the majority of person, high intensities of luster are extremely desirable. The brilliancy of diamond is a principal factor in making it one of the most desirable of all gems. In other varieties of stones, also the highest luster possible is almost always the most desirable. Gemstones fashioned in the Orient are often poorly polished, hence, luster is affected. However, the subdued lusters of some turquoise and jade appeal more to some people than a more brilliant luster.

The luster of diamond is very distinctive. However, a poorly-cut and polished diamond, compared with a well-cut and highly polished zircon observed at a short distance in a brilliant light and judged by luster alone, might deceive even an expert. Luster as a means of identification is helpful in separating a well-polished stone of adamantine luster or one with a greasy luster (such as jade) from other gems; but the variations in polish make luster a doubtful means of identification, except to the more experienced. A knowledge of the luster of rough and broken minerals assists the gemologist in identifying uncut stones. Also, fractures on cut stones reveal broken surfaces that can be examined for luster under a loupe. This is especially useful in separating turquoise and chalcedony from glass imitations. The luster difference between the two parts of a garnet-and-glass doublet is also useful; a very definite difference between the garnet top and the glass base can be noted, usually on the crown facets.

VII. TRANSPARENCY.

The transparency of a gem depends on the quality and quantity of light that is transmitted (allowed to pass through) by it.

A. Quality of Transmitted Light.

The quality of light trasmitted by a gem depends on the "obstacles" such as minute imperfections or peculiar structure, that it encounters during its passage through the stone. If light were allowed to pass through a gem without any distortion or absorption, it would be classed as perfectly transparent. Actually, no substance is completely transparent.

B. Quantity of Transmitted Light.

Light may pass through a substance with no appreciable distortion, yet it may, because it absorbs much of the light, be classed as not completely transparent. For example, a strongly colored gem such as a dark-red garnet absorbs much light; therefore, it does not exhibit maximum transparency. The amount of absorption varies from a very small percent absorbed in transparent stones, such as diamond and rock crystal, to almost complete absorption by black chalcedony.

The degree of transparency of a gemstone is described by the following terms:

A. Transparent.

Gems through which light passes with no appreciable distortion and/or absorption are said to be transparent. Images can be seen clearly through transparent stones. Examples are the finest qualities of diamond, ruby, emerald and rock crystal quartz.

B. Semitransparent.

Those gems that show a small amount of absorption and/or distortion of transmitted light are classed as semitransparent. Images can be seen through semitransparent gems, but they are not as clear and sharp as those seen through transparent stones. Examples are some varieties of amber and precious moonstone.

C. Translucent.

In order to be classed as translucent, a stone must show a certain amount of distortion and/or absorption of light, but it will pass a large quantity of the light that enters it. A good example is white chalcedony.

D. Semitranslucent.

Gems classed as semitranslucent suffer a large amount of both absorption and distortion; therefore, they pass very little light. As a rule, light penetrates only through thin sections of these stones. Examples are obsidian and amazonite.

E. Opaque.

When cut as gems, many minerals, such as black chalcedony and lapis-lazuli, are opaque, since in thicker pieces they transmit no light. In the strictest sense of the word, only those substances that show metallic lusters can be classed as opaque, since any other substance, if cut sufficiently thin, will show SOME transmission of light. Examples of metallic opaque minerals are pyrite and marcasite.